# Mobile capture of remote points of interest using line of sight modelling

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# Mobile Capture of Remote Points of Interest Using Line of Sight Modelling

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Abstract

Recording points of interest using GPS whilst working in the field is an established technique in geographical fieldwork, where the user's current position is used as the spatial reference to be captured; this is known as *geo-tagging*. We outline the development and evaluation of a smartphone application called Zapp that enables geo-tagging of any distant point on the visible landscape. The ability of users to log or retrieve information relating to what they can see, rather than where they are standing, allows them to record observations of points in the broader landscape scene, or to access descriptions of landscape features from any viewpoint. The application uses the compass orientation and tilt of the phone to provide data for a line of sight algorithm that intersects with a Digital Surface Model stored on the mobile device. We describe the development process and design decisions for Zapp present the results of a controlled study of the accuracy of the application, and report on the use of Zapp for a student field exercise. The studies indicate the feasibility of the approach, but also how the appropriate use of such techniques will be constrained by current levels of precision in mobile sensor technology. The broader implications for interactive query of the distant landscape and for remote data logging are discussed.

Keywords: Digital Surface Models, Mobile Field Guide, Mobile Learning, Location Based Services, Line of Sight, Viewshed, Intevisibility

## 1.0 Introduction

Geographic Information Systems (GIS) have long been confined to the desktop, due to the processing requirements of the tasks they perform and the storage requirements of the datasets used. Geographic Information Science (GISc) has developed within the paradigms of this desktop environment, and as a consequence the field as a whole has been heavily influenced by the modes of interaction brought by that environment. This began in the 1980s with the digitisation of paper maps, using tables or onscreen capture from scans. Through the 1990s field survey devices prevailed, typified by real time kinematic GPS, with data being captured at sub centimetre ground accuracies (Ordnance Survey, 2010). In parallel, geographic content creation has flourished, with the emergence of Web 2.0 producing an explosion in user generated content through crowd-sourced applications such as OpenStreetMap (OSM)[1]and Wikipedia[2], via geo-tagging on sites such as Facebook and Twitter, and indirectly via location based leisure activities such as geo-caching (O'Hara 2008) utilising mobile devices.

Until recently, the hardware available to developers has restricted the development of robust applications capable of fully exploiting the user's location in an outdoor environment. The development of the *smartphone* has provided consumer handheld multimedia computers which, along with the advent of software application (*app*) stores, allows developers to create and distribute programs for use in the field by anyone with access to an appropriate mobile device. New design challenges for human computer interaction on small touch-screen devices emerged, promoting simplicity of interface and a focus on the delivery of a core set of tasks. In addition, modern mobile devices now carry a variety of sensors including positioning technology, accelerometers to measure tilt, digital compasses, dual cameras, as well as 3G connectivity that allows access to the web from anywhere with network coverage. The convergence of these technologies on powerful multimedia mobile devices offers opportunities for developing new forms of information capture and display in the field.

Previous geo-tagging applications have predominantly relied on the user being physically situated at the location for which they wish to record information. This can include the capture of discrete features such as paths or buildings as in the case of OSM, but also the capture of general notes relating to a place as with the GeoNotes application (Persson et al., 2001). Similarly the user's current geographic location has tended to be the focus when designing techniques for the retrieval of information via Location-Based Services (LBS). There are instances, however, where the focus of interest for either recording or retrieving information is not the user's current location, but some distant point on the landscape. Examples include logging the location of the focus of interest when taking a photograph, marking points along the tree line of an adjacent valley side, or finding the map location of a distant landform or building. Potential use cases include tourists finding the names of distant mountains or villages, or allowing geology students to query the rock type of any distant point on the landscape surface. To achieve this presents numerous technical challenges: the app on a mobile device must capture accurately not only its current position, but also orientation, height and line of sight, so as to calculate the intersection of a line in 3-dimensional space with a digital model of the landscape as illustrated in Figure 1.

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[1] www.openstreetmap.org
[2] www.wikipedia.org

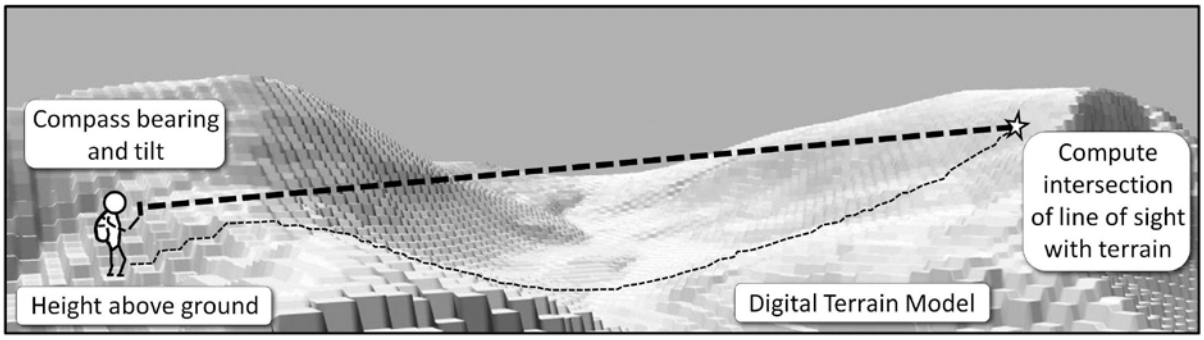


Figure 1. Remote capture and query via a mobile device

This paper presents a software application called *Zapp* which determines the geographic coordinates of points on the distant landscape using the intersection of a line of sight from the mobile device with an on-board digital surface model. Using this mechanism, Zapp allows a user to record notes relating to a remote location and also to retrieve information that has been stored for that remote location on the landscape. The application adopts a simple user interface based on a *camera metaphor*, using a crosshair on the camera view to define the user's target. The current position, orientation and tilt sensor readings from the device are then used to calculate a line of sight which is intersected with an on-board Digital Surface Model (DSM) to determine the coordinates of the target. These coordinates are then used either to geo-tag notes relating to the target point, or as part of a query operation to display information related to the target point. We place the technique in its academic context, presenting the theoretical and architectural underpinnings of the application. We also assess the general utility of Zapp, presenting a systematic set of experiments designed to understand the nature and magnitude of errors in the locations of the target points, along with the results of a trial undertaken on a fieldtrip to the Lake District, UK. The work follows on from a previous study that focussed on the use of mobile technology to augment landscape scenes with additional information in the context of field trips and mobile visitor guides (Priestnall et al., 2009).

## 2.0 Background

For many applications the focus is on capturing detailed domain-specific information for points in the field, often requiring close inspection or direct survey, for example in field geology (Dey and Ghosh, 2008). The purpose of Zapp is to allow the mobile capture and query of points on the landscape that are remote but visible from the user's current location. There is a particular requirement, therefore, to model the area visible to the user, to enable this broader landscape context to represented computationally.

An early approach to modelling visibility was the use of *isovists*, having their origins in architecture, typically representing the area visible from a given point, by intersecting lines of sight with 2D geometries of neighbouring buildings (Benedikt et al., 1979). Similar techniques can be implemented in a mobile search context by restricting search findings to the user's field of view, as with Simon and Fröelich (2007) who model faces of buildings, or as the authors termed it, *billboards*, using extruded map polygons. Such vector techniques are efficient and therefore suitable for implementation on mobile devices. But in many landscape contexts the vector geometry on a flat plain is too simplistic, and does not recognise that the ground itself can play an important role in visibility calculations. At this point the type of visibility algorithms used with continuous grid-based Digital Surface Models (DSMs) in a GIS context becomes relevant.

LoS algorithms are common functions in raster-based GIS, allowing both individual calculations of visibility between two points, and also the derivation of areas of visibility (*viewsheds*) from one or more points. LoS calculations, including viewsheds, remain typically binary in terms of whether something is visible or not, although some have proposed more probabilistic viewsheds to acknowledge uncertainty in the surface models being used in the calculations (Fisher, 1995; 1996). Viewsheds have been used to assess view quality (Germino et al., 2001), to understand levels of compensation when implementing energy policy (Groothius et al., 2008) and to address problems of coverage in cellular phone networks with multiple stations (Kim et al., 2004). Viewsheds have also been used to model how well an object or area can be recognised at distance (Ogburn, 2006). Such applications of viewsheds are typically developed and deployed on desktop machines, although the use of pre-generated viewsheds to filter the delivery of media on mobile devices is described by Bartie et al. (2006) in a speech-based visitor guide for Edinburgh, and by Karpischeck et al. (2009) to determine which mountain peaks are in view in the SwissPeaks mobile augmented reality (*AR*) app. These applications contain a database with viewsheds from each pre-specified feature of interest to indicate whether that feature is visible or not from the user's location, so they do not enable arbitrary landscape points to be logged.

The virtues of employing rapid visibility modelling in filtering information presented to a mobile user in the context of LBS are discussed by Mairhoffer et al. (2007). Viewsheds which acknowledge varying degrees of visibility through specific land covers have also been explored, for example the concept of the *visualscape* defined as "the spatial representation of any visual property generated by, or associated with, a spatial configuration" (Llobera 2003, pp.30), where the spatial representation is defined as the way a visual property is stored and represented.

Mobile applications designed to support a direct interaction with the scene around the user have been termed Spatial Information Appliances (SIA) by Egenhofer (1999) and are characterised by functions such as: accessing information related to Points of Interest (PoIs), adding content to PoIs, navigation and exploration. There are various approaches to portraying information about PoIs relative to position of user and Fröehlich (2006) outlines four potential methods: pointing the device; map; radar style (a compass with the relative locations of PoIs overlaid); and AR. The study by Fröehlich devised a controlled simulation comparing all four techniques and results suggested that users preferred pointing the physical device at the PoI to be selected, closely followed by the AR method.

AR browsers such as Wikitude[3] and Layar[4] make use of the orientation sensors in the device along with proximity filters to overlay PoIs of a particular type on the camera display, but these are not necessarily features that the user will be able to see. Additional maps showing the PoIs in relation to the user's location aim to assist them in deciding what is relevant, and Pombino et al. (2010) employed an additional interface feature offering pre-prepared library images of particular PoIs that should match the view from the user's current position.

[3] www.wikitude.org
[4] www.layar.com

Visual scene recognition approaches have focussed on the visual salience of objects in the scene, where the user has the generic question ‘What is that I can see over there?’ For example Google Goggles[5] analyses a library of images of nearby features for a match against the current camera image (Amato et al., 2010). This method, while successful for informing the user about visually salient pre-stored landmarks, is not suited to logging arbitrary points on the visible landscape. Geographical fieldwork often requires logging of non-salient points in the landscape, for example the rock type associated with a particular point on the ground, where the user may utilise a range of evidence and experience in deciding what to log, and there are not necessarily any visually salient features involved.

The necessary technologies have now converged on smartphones to allow the exploration of more sophisticated in-field geospatial queries. Bilandzic and Foth (2012) review research exploring the relationship between the user, their mobile device, and their current geographic location, including the use of deliberate directional queries, often termed Mobile Spatial Interaction (MSI). These techniques can combine GPS and orientation sensor information to intersect a line of sight with digital representations of the features of interest around the user. Such *Geo-Wands* (Egenhofer 1999) have the potential to offer outdoor equivalents to pointing devices developed for controlling indoor appliances in a smart home setting, as seen in the World Cursor (Wilson and Pham, 2003). Robinson et al. (2009) describe the *Sweep-Shake* device that offers haptic feedback when directed towards geo-tagged information and Lei and Coulton (2009) used a flashlight metaphor for displaying on a map the search area being pointed at. Such an approach goes beyond a simple ‘where is my nearest’ search by offering directional queries, but does not attempt to filter by visibility. Carswell et al. (2010) describe a technique that combines a directional flashlight search with visibility filters, using visibility modelling techniques based on 3D building geometry. Using 3D building geometry to account for visibility typically requires a client/server relationship due to current limitations in mobile geospatial databases (Yin and Carswell, 2012). Oracle offer the ability to check for LoS intersection, but this type of querying is limited to a bounding cube of an object, which makes high grade queries difficult and still has the requirement for discrete objects with defined geometry. Whilst these approaches take account of visibility in the form of 2D billboards or 3D objects they do not consider the underlying topography of the landscape. By contrast, Zapp utilises an LoS algorithm operating on a continuous surface model allowing the terrain to influence the visibility calculations, enabling it to include situations where there are no salient or prescribed objects or features, so allowing any point on the visible landscape to be tagged or queried.

## 3.0 The Zapp application

The Zapp application aims to provide a general solution for users wishing to ‘Mark the location I’m looking at’ and to answer the related query ‘What are the properties of that point on the landscape over there?’ Both are underpinned by the remote survey technique of intersecting an LoS with a DSM to give the coordinates of the target point defined by the crosshair in the camera view. The coordinates are either used to geo-tag a note relating to what the user is looking at, or to initiate a spatial query to discover if there are any pre-stored properties associated with that point on the landscape. Those properties are currently defined by a grid of values at the same resolution as the terrain surface model and can be authored in such a way as to represent discrete patches of ground (which may relate to ‘features’ of some kind) or as continuous fields, in a similar way that raster datasets found in desktop GIS can be used to represent a wide variety of surface properties. All processing and data representation

[5] http://www.google.com/mobile/goggles

occurs on the mobile device. This is not simply the implementation of a desktop LoS calculation on a mobile device. It requires consideration and attenuation of errors introduced through GPS positioning, tilt, compass orientation, height, and camera shake, as well as issues of human-computer interaction design and usability in the field. We propose that this method of remote tagging and query will have broad applications in leisure and tourism as well as specific uses such as field trip learning.

The basic functional requirement of Zapp was for a mobile application capable of capturing the coordinates of a point on the ground anywhere in the landscape scene. Zapp is therefore designed to be a simple experimental platform through which to assess whether these basic functional requirements can be implemented on a commercially available mobile device. The users of the current system are therefore researchers and also students on field trips, acting in part as design informants.

The user requirements (with associated system requirements) are:

- determine the orientation by pointing the mobile device (orientation sensor);
- determine angle of inclination/declination of device (tilt sensor);
- use the camera view to specify and record the target point (camera);
- extract the coordinate of the target point (GPS to give coordinates of user's position, a software implementation of an LoS algorithm, and a DSM of the area);
- undertake the above in areas with little or no mobile connectivity (sufficient on board processing power and data storage capacity to undertake all calculations in real time on the device).

Modern mobile devices have the computing power to undertake the LoS calculations on board. This, coupled with the issues experienced in remote environments with 3G data connectivity, led us to implement a simple LoS algorithm that has no network requirement and can be processed on the device. A simple binary LoS is suitable for this type of task, providing rapid feedback to the user and offering the ability to capture or query multiple points in a short space of time. Other viewshed methods such as probabilistic (Fisher 1992) and fuzzy (Fisher 1995) were not implemented at this time due to their methodologies being optimised for the derivation of spatial viewsheds rather than point to point calculations.

### 3.1 Algorithms and data

Central to the success of the application was an adaption of the LoS algorithm (Fisher 1996) which has been used as part of intervisibility calculations in a desktop GIS context. The algorithm is often used as a means to an end to derive grid-based visibility maps of various kinds, where each cell in the grid is assigned a value indicating the degree of visibility, or the closeness to being visible. At the core of these approaches is a check to assess whether terrain cells located between an observer and a target point rise above the LoS vector connecting those two points. In the case of Zapp, the geometry of a LoS is determined by the sensors on the phone at the moment when the user chooses to capture a point. Working away from the user's location in the direction of the LoS, the first terrain cell whose elevation intersects the LoS defines the coordinate of the captured point.

The algorithm works as follows:

1. Get position, tilt, orientation and height of device, with height pulled from the device position on the surface model, raised 2 metres to simulate device height from ground.

2. For each cell in the direction of the given orientation calculate projected height given tilt, at increments equal to raster cell size.
3. If calculated height at current point > height value of cell at current point then go to next cell.
4. If height at current point < height value of cell at current point, this is the DSM cell being ‘Zapped’.

An outline description of this implementation and early test runs around the University of Nottingham campus using a range of resolution DSMs derived from the original LiDAR 50cm dataset can be found in (Meek and Priestnall, 2011). For the version described in this paper the study area was the more open landscape of the English Lake District, so inevitably a much larger geographical area was required. Calculating a composite viewshed in ArcGIS representing the area likely to be visible from the ‘on the ground’ field site helped us define the geographical extent of the terrain data required. After experimentation, the 5m resolution radar data covering the field site was degraded to 20m to create a manageable array size (700 x 700 = 490,000 cells) for processing on board the mobile device. This resolution allowed a DSM of the entire geographic area to be stored on the phone and still leave enough memory to run the application, take photographs and multitask with the device’s photo gallery and other applications. Although current technology only allows arrays of this magnitude, future devices should be able to hold much larger arrays allowing for higher-resolution datasets. The study area is shown in figure 2.

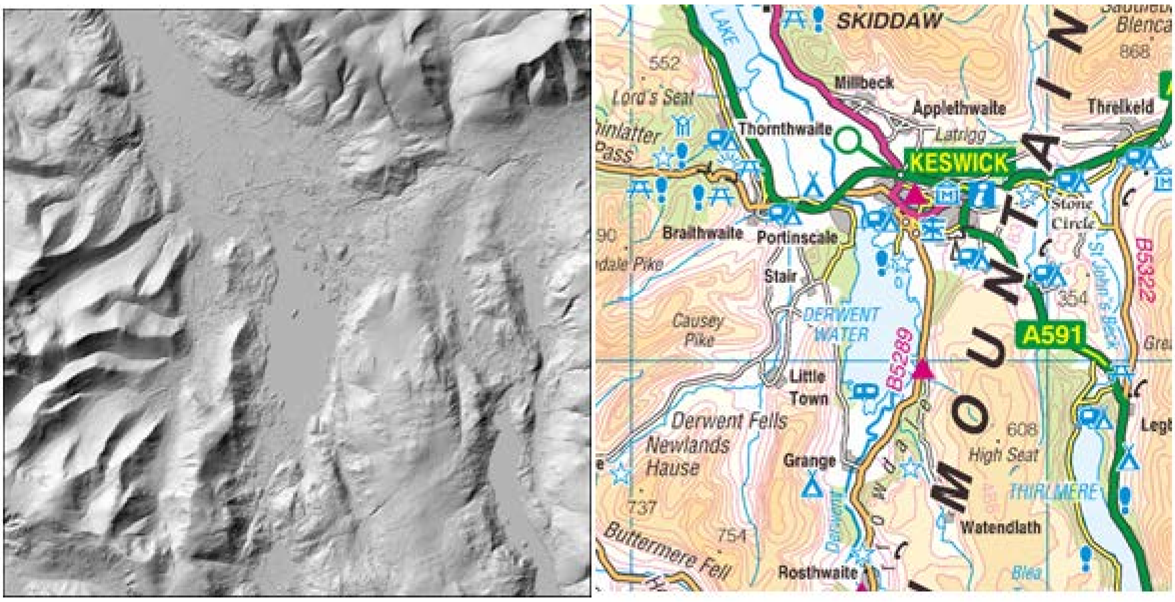


Figure 2: Lake District Study Area. Left: Hill shaded version of the radar data, Right: Ordnance Survey 1:25,000 raster (© Ordnance Survey).

## 3.2 Implementation

Zapp was implemented for the Android operating system due to its openness for development and the large support network at the University of Nottingham, along with large numbers of handsets available for testing. Upon opening the Zapp application the user is presented with a map of the study area that can be panned or zoomed, like a webpage but stored locally on the device. In addition to the Ordnance Survey (OS) base map (Figure 2, right), the application allowed users to look at a relief map derived as an image from the radar data (Figure 2, left). At any time the locations of any captured points could be viewed over one of these base maps. The *capture mode* of the application (in the Lake District environment) can be seen in figure 3, through which remote points can be captured by aligning the central cross with a point on the landscape as seen through the camera view and pressing the ‘Capture Point’ button.


Figure 3: Zapp interface

The points are saved in a text file stored on the device, an example of which can be found in table 1.

| c | Device X | Device Y | Device Height | Orientation | Device Tilt (degrees) | Target Easting | Target Northing | Target Height |
|---|---|---|---|---|---|---|---|---|
| 74 | 324620 | 521136 | 145 | 144.23 | -2.09 | 324680 | 521020 | 148 |
| 32 | 324025 | 521055 | 124 | 134.43 | 3.9 | 324200 | 520860 | 127 |
| 34 | 324026 | 521054 | 124 | 136.75 | -3.46 | 324200 | 520860 | 127 |
| 6 | 323715 | 521164 | 104 | 3.98 | 15.85 | 323700 | 521220 | 107 |
| 5 | 323715 | 521164 | 104 | 6.09 | 15.87 | 323700 | 521200 | 107 |
| 75 | 324620 | 521136 | 145 | 154.99 | 0.01 | 324660 | 521020 | 148 |
| 73 | 324620 | 521136 | 145 | 145.11 | -3.95 | 324700 | 521000 | 148 |
| 6 | 323710 | 521155 | 107 | 336.18 | 0 | 323660 | 521220 | 110 |

Table 1: Example output from Zapp, with formatting and column labels added for clarity.

In *query mode* the ‘Capture Point’ button is changed to ‘Query Point’ and Zapp performs the LoS calculation to determine the point of interest indicated at the centre of the screen. This is then used to query an information layer represented as a raster dataset covering the same area as the DSM. Each cell in this raster layer is encoded with a reference number which can be associated with a media element which is activated and displayed on screen. Such encoding gives flexibility in representing *areas* of interest as groups of cells with the same value, which can be discrete or can form continuous coverage over the whole area.

## 4.0 Controlled Testing of Zapp

A series of experiments were designed to help us understand the nature and magnitude of errors associated with the system as it stands. We first present a summary of a controlled experiment to understand the errors associated with the sensors on the mobile devices that were subsequently used in the field. Then we describe a field experiment to systematically capture known points and compare resulting coordinates with reference map coordinates forms the basis of the evaluation.

### 4.1 Errors from the device sensors

To underpin the analysis of errors experienced in the field, we performed systematic testing of the sensors on the mobile devices being used, in this case the Google Nexus S. The three sensor types used in the LoS algorithm are GPS, tilt sensor and compass. The GPS receiver was tested by positioning the device (on a tripod to remove human camera shake) at locations identified in aerial photography at 10cm resolution. The tilt sensor and orientation sensor were tested by orienting the device perpendicular to the normal axis and facing north using a high grade compass and spirit level. 400 readings were taken from the device and the process was repeated for three separate Google Nexus S devices. The results are shown in table 2.

| Sensor | Mean Error | Standard Deviation | Max |
|---|---|---|---|
| GPS | 6.81 | 5.09 | 31.22 |
| Compass | 1.02 | 0.90 | 3.28 |
| Tilt | 1.05 | 0.75 | 2.41 |

Table 2 Errors for each sensor type, GPS is in metres, compass and tilt in degrees.

Although the errors experienced in the device at rest are small, over a distance of 1Km with the device 100m above the target point, the tilt sensor can introduce an error of -156m or +227 (depending whether the error is positive or negative) distance from the true location, and the compass can introduce around ±17m of error, assuming a flat surface. Clearly in an upland study area such as the Lake District the influence of this sensor error may be less in many cases due to target points falling on parts of the landscape less oblique to the observer's viewpoint, such as hillsides. Nevertheless this type of error should be borne in mind not only for the reliability of geo-tagged points on distant flat landscapes but also the implications for authoring information layers designed to be queried using this technique.

### 4.2 Field-based evaluation of remote point capture

A field experiment was undertaken in the Lake District study area, where three researchers attempted to pick out known target points of varying distance, relative height to viewer and type. In these experiments the researchers each had a device running Zapp and walked along a prescribed route with stops at observation points roughly every 100 metres. At each of these observation points, the researchers agreed on three target points on the landscape, in this case salient features that could be located on a map to provide reference data, each researcher capturing five points for each target. For the purposes of defining a set of reference target points we chose features such as mountain peaks, buildings, crags, and islands on Derwent

Water. A total of 468 points were captured using the devices in the field, there were 22 different targets captured from 12 different observation points along the prescribed route.

It was clear from the data capture exercise that there were three broad categories of target based upon the reliability with which the three researchers could identify the specific target points. The types of targets were referred to as peak, defined points and undefined points – examples of which are shown in Figure 4. The peak category consists of mountain peaks as seen from the observer’s point of view, although if viewed from a point near to the mountain these may be closer ‘false peaks’ rather than the highest point of that mountain as represented on a map. The defined points are those that can be easily defined and recognised from varying distances; an example is “the gable end on the white house in Little Town”. Undefined points are those that are more open to interpretation such as “the centre of the large island in Derwent Water” or “midway along that crag across the lake”.

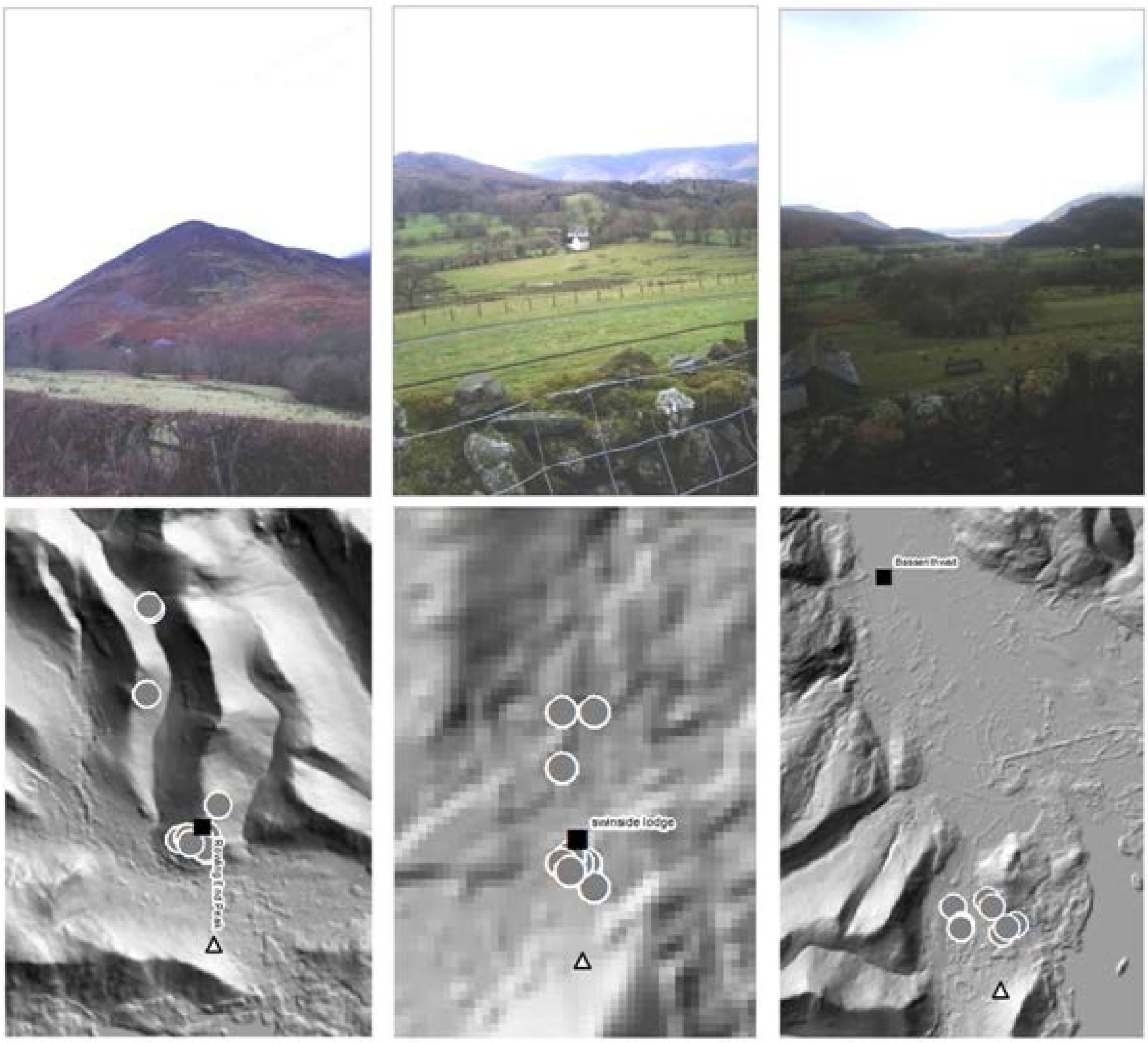


Figure 4: Examples of the three classes of target, with photography from mobile device above, and captured points (circles) from observer (triangle) to target (square) mapped below. From left to right: Peak (Rowling End) , Defined target (Swinside Lodge Guest House), Undefined target (shore of Bassenthwaite lake).

Before presenting the results from the experiment there were a number of general observations to be made which impact on the overall utility of the method and the positional accuracies obtained.

### 4.2.1 Instances of LoS missing the surface model

This occurs when the device attempts to record a point close to the skyline and the LoS algorithm misses the surface model entirely, for example when the device is pointed towards a mountain peak.

Table 3 shows the number of attempts at capture at each type of target, a successful capture being where the LoS algorithm intersects with the surface model and an unsuccessful capture is where it does not. It can be seen that the majority of misses were aimed at peaks, which is to be expected, as when one is facing a peak it is more likely to be the highest object in its line of sight, meaning that if the peak is missed there is no more of the DSM behind it, therefore the surface model is missed completely. Although not implemented for this test, a minor change could be made to the algorithm so that the considered point is snapped to the surface model where the missed point is closest, thus removing unsuccessful capture errors.

| Target Type | Unsuccessful Capture | Successful capture | Total |
|---|---|---|---|
| Peak | 61 | 77 | 138 |
| Defined | 17 | 175 | 192 |
| Undefined | 5 | 133 | 138 |
| Total | 83 | 385 | 468 |

Table 3: Number and types of target.

### 4.2.2 Representational fidelity of the surface model

Given the importance of the continuous DSM in determining visibility via the LoS the representational fidelity of the model will influence the reliability of the technique. Due to resampling, some of the smaller features, such as buildings, are smoothed out of the model completely. Also, the observer's height can be either raised or lowered due the observer's position being incorrectly placed above a neighbouring cell in the model. Figure 5 illustrates this point, where the 20m DSM cells are visualised as columns. Not only is the target building smoothed considerably but slight positional changes in the observer point highlighted, perhaps due to GPS wander, would cause the neighbouring cell height to be used, effectively raising the observer and resulting in a likely overshoot in the capture procedure.

Figure 5. Example of the representational issues present with the DSM. The photograph (left) as taken from the location indicated in the 3D visualisation (right).

4.2.3. The DSM blocking effect

Several capture attempts experienced a blocking effect from the DSM when attempting to capture points that require the device to be pitched downwards. This happens when the surface model is generalised such that artefacts from the radar data, or through the resampling process on the surface model, extend further than the actual feature in the real world (i.e. because they are represented as straight-edged blocks rather than curved shapes, see figure 5). When the user is positioned on top of one of these affected features, the raster cells can block the line of sight algorithm prematurely, resulting in a captured position that is very close to the observer point. This effect also occurred when attempting to capture a PoI in the distance when looking past a landscape feature such as a hillside which overextended its true size in the surface model.

4.3 Results from the field exercise

After removing the points that missed the surface model, those caused by the blocking effect and where the user is attempting to capture a distant point beyond the bounds of the surface model, Table 4 shows the points that fit into each error category. The number of points remaining for use in the error calculations is 299.

| Target Type | Total Points | Unsuccessful Captures | Blocking Effect | Points outside the bounds of the DSM | Total considered Points |
|---|---|---|---|---|---|
| Peak | 138 | 61 | 7 | 15 | 55 |
| Defined | 192 | 17 | 23 | 11 | 141 |
| Undefined | 138 | 5 | 20 | 10 | 103 |
| Total | 468 | 83 | 50 | 36 | 299 |

Table 4: Types and numbers of errors experienced for different target types.

Table 5 shows the number of points, mean error and standard deviations for each of the target types for the considered points at varying distances to the target. The error was calculated as the straight-line distance between the location of the point that was captured and the location of the mapped landmark taken from Ordnance Survey data. It is clear that the defined features had less error than those features that were either peaks or undefined in the landscape.

(a) Number of captures per type

| Type of Point | <1km | 1-2km | 2km+ |
|---|---|---|---|
| Peak | 26 | 17 | 12 |
| Defined | 86 | 38 | 17 |
| Undefined | 25 | 56 | 22 |

(b) Mean error (m)

| Type of Point | <1km | 1-2km | 2km+ |
|---|---|---|---|
| Peak | 339 | 436 | 2590 |
| Defined | 100 | 375 | 650 |
| Undefined | 364 | 924 | 2571 |

(c) Standard deviation (m)

| Type of Point | <1km | 1-2km | 2km+ |
|---|---|---|---|
| Peak | 71 | 248 | 350 |
| Defined | 258 | 575 | 881 |
| Undefined | 112 | 1059 | 2073 |

Table 5: Calculations for different distances from target point.

A combination of the known sensor errors and user hand shake would lead us to expect an increase in error with distance from the user. Figure 6 shows the relationship between the distance to target and the positional error, which is significant, positive and strong (0.834 Pearson R). It must be noted that many of the undefined points were far away which resulted in the device being positioned at an oblique angle. Due to their distance, it also meant that the feature being captured appeared as a very small point on the screen making it difficult to pinpoint the exact point of capture. The statistics calculated for the peak category were taken from the OS map location for the highest point on the hill or mountain, which may not be visible peak from the observer point on the ground, introducing further error. When the device is within a kilometre of the target, the error reduces to 100m for defined targets, which gives a useful indicator of what can reasonably be expected of this technique given its implementation for this scale of study area using a 20m DSM.

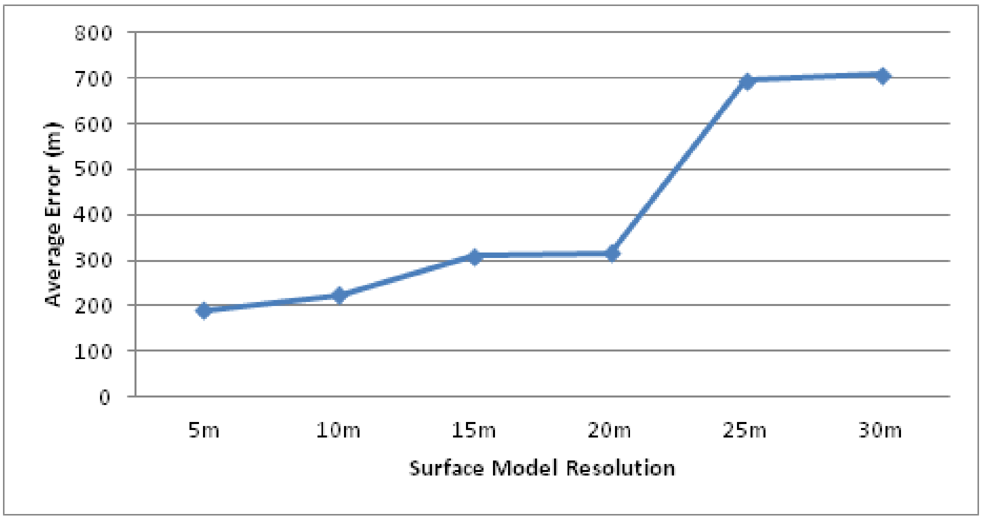


Figure 6. Graph of Distance versus Error.

The large study area and the desire to implement the technique entirely on the device led to a choice of a 20m DSM, but clearly alternative implementations or future improvements in storage and processing capacity would allow higher resolution models covering the same area. We did however run a desktop study to indicate the likely impact that higher-resolution DSMs may have on the positional accuracy of captured points. Using the LoS start and end positions from the field experiment we systematically changed the cell resolution of the DSM used from 5m to 30m and calculated differences between computationally derived intersections and intended target points. Figure 7 shows overall average error at various DSM resolutions. It can be seen that any further degradation of the DSM to 25m or 30m may result in dramatically increased error, although to reduce error we would need to consider resolutions of 10m or less. Given the current constraints for storing and processing DSMs on the device it would appear that for this scale of landscape and study area a 20m DSM resolution was an acceptable compromise.

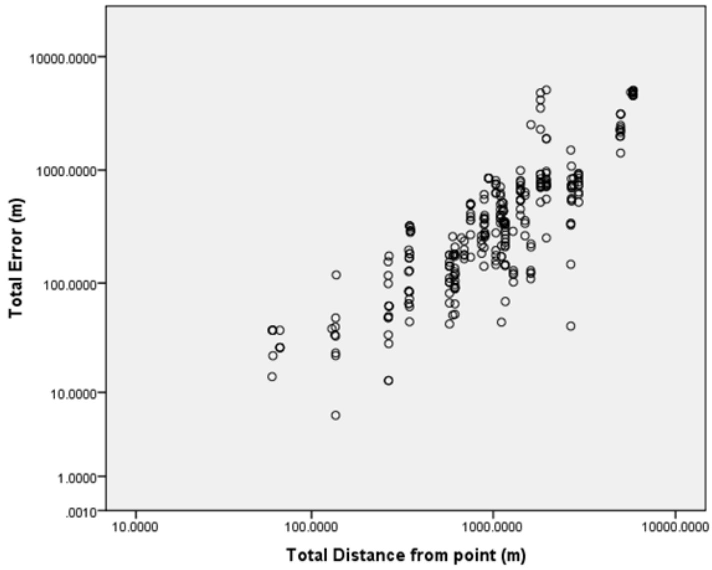


Figure 7. Impact of DSM resolution on average error.

## 5.0 Field trip trial

To complement the systematic testing of Zapp by the researchers we incorporated its use into a fieldwork exercise as part of the four-day residential field course module ‘Mobile and Field GIS’, taken by third year undergraduate Geography and Masters Level GISc students at the University of Nottingham. The objective of this module was for the students to investigate the capture of geographic information in the field, including an evaluation of relevant mobile technology. The 24 students taking part were familiar with GISc from previous mandatory modules. A day exercise featuring Zapp was designed to allow the students to experience the basic remote capture facility as well as to assess the general usability of the technique. The study area was identical to that used in the systematic testing previously discussed (shown in Figure 2) and whilst the total area was around 200km$^2$ the students were only required to attempt capture within a small area (approximately 2km x 2km) central to the study area.

The guidance for the exercise focussed on the requirements for in-field mobile guides and a number of techniques for capturing and delivering content in the field were discussed. The students were informed that the specific purpose for including Zapp in the field exercise was for them to evaluate its value as a tool for creating geo-located content for mobile field guides, by capturing remote points of interest in the landscape. It was made clear that when the ‘capture’ button was pressed, as well as capturing the coordinates of the remotely surveyed point the application also stored an image of the screen camera display. They were asked to use these photographs to illustrate the notes they made of the intended targets. The groups spent around five hours in the field and were also loaned a video camera, digital still cameras and audio recorders to capture their experiences in the field. After the field portion of the day was completed, the groups returned to the local field centre to analyse their data and organise it into group presentations that formed their assessment for the module.

## 5.1 Results

In order to get a reasonable understanding of how Zapp performed in the field, in the context of capturing remote points of interest, we utilised positional log data and photographs from the devices, combined with direct observations and discussions with the students. In all, four sets of positional points were considered, one set from each of the student groups, giving 73 points in total. The captured points shown in figure 8 indicate a dispersal of points across the study area, although most relate to large physical features such as peaks and lake islands. Table 6 shows some summary data of distance and elevation of the target points relative to the location of the device. In general, Zapp was used to capture objects in the middle distance as compared to the size of the study area. Figure 8 shows a cluster of captured points around the walking route, with the majority of points falling within 1 km of the route travelled by the student groups. The small median height change suggests that students tended to capture points that were roughly at eye level.

| | Distance(m) | Height Change(m) |
|---|---|---|
| Mean | 922.19 | 17.44 |
| Median | 38.93 | -0.80 |
| Maximum | 6597.41 | 512.00 |
| Minimum | 0.51 | -184.66 |

Table 6: Summary statistics of points captured by groups

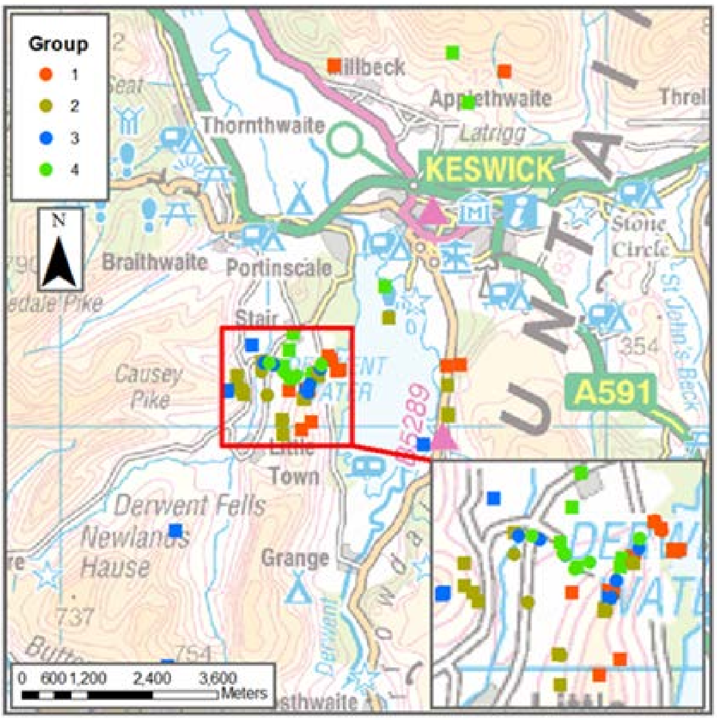


Figure 8: Sample of points captured during field trip trial. The box indicates the area of ground covered by the students. Squares show points captured by devices, circles show location of the device at the time of capture.

Generally, the students found Zapp easy to use due to its minimalist design and small number of features. As Zapp could put into 'sleep' mode, a typical use of the device was to remove it from the pocket, wake the app, capture a point, sleep the app and then return it to the pocket – a similar workflow to making a phone call or sending a text message. This meant that usage of Zapp tended to follow a natural usage of mobile devices on the move rather than being seen as a specialist piece of surveying or logging equipment, and little obvious frustration was observed.

5.2 Reflections on the field test

Comparing the student experiences to the systematic testing, the students also experienced problems with the raster blocking effect and with smoothing of features such as the islands within Derwent water. They did not report a high level of error in the points captured when compared to their intended targets, perhaps due to the relative proximity and size of features they chose to capture, as compared to the field-based evaluation presented earlier which sought to test accuracies across the full range of distances from the user. The collection of photographs associated with the captured points suggest that many of the targets for point capture were prominent features that were easily visible on the device screen. Environmental conditions on the day of the field trip trial were favourable, with only screen glare being an issue. Clearly, if there had been wind or rain this may have hindered the capture process and affected the levels of frustration experienced in completing the task.

6.0 Design implications

From the findings of the two tests of the system, specific design implications emerged relating to the future use of Zapp and similar applications. First, the simple interface was a success and there was a minimum of frustration, with very little support required during its use. However, the actual capture of point-based data in the field was prone to significant error at distances greater than 1km, due to a combination of sensor error and the difficulty users had in precise targeting using the small screen, particularly when viewing the distant landscape at an oblique angle. The accuracy with which distant points can be captured relates to the separation of adjacent DSM cells when projected onto the device screen. This in turn is a function of distance from the observer and the angle of incidence of the LoS when intersecting with the DSM. It is clear that the technique is not suited to high grade surveying tasks such as marking a tree line or the boundary of a field, but it shows promise for tagging larger landscape units.

Figure 6 shows a positive relationship between the resolution of the DSM and the accuracy of the capture. Currently, the storage and processing power of a smartphone require a DSM resolution of 20m for a study area of greater than about 5km x 5km. For smaller urban or semi-urban environments the DSM can have a finer resolution, which also allows for a more faithful representation of salient features such as buildings. For example a 2m LiDAR DSM representing a $2km^2$ area for a University campus would require the same data storage as the 20m resolution DSM used in this $200km^2$ study area. Also, the features of interest for which users capture points are likely to be closer and smaller, for example buildings, but in terms of their prominence in the field of view may be similar to larger more distant features such as mountains when modelled at a course resolution. This issue of scale and the use of Zapp in urban areas is a subject of ongoing study.

The tests presented in this study have also helped to inform the way information layers for use in query mode should be designed. The combination of factors contributing to accuracy of remote capture ultimately require that any areas of the landscape given properties in a query layer should be large enough to clearly discernible when mapped onto the device screen. These could be discrete areas representing features of interest such as settlements, mountains or lakes, or continuous coverage of surface properties made up of large contiguous areas such as soil type or geology. Figure 9 shows two such examples developed for use on further field trip exercises. In terms of scenarios for using Zapp, when capturing points of interest, or authoring information layers to be used in query mode, the foci of interest on the landscape should either be well separated and clearly discernible on the device screen, or should be large areas for which the midpoint could be captured.

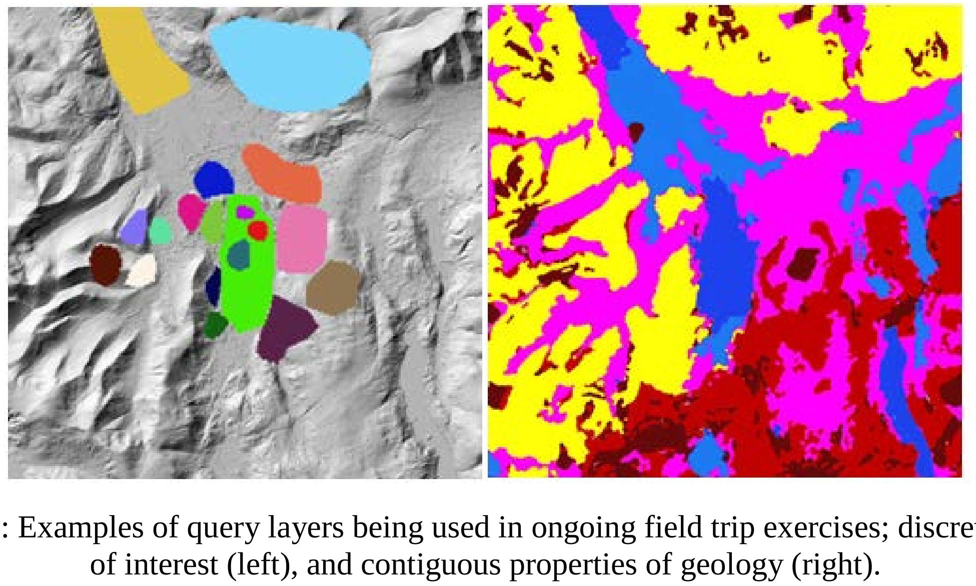

Figure 9: Examples of query layers being used in ongoing field trip exercises; discrete zones of interest (left), and contiguous properties of geology (right).

## 7.0 Future work

We have shown that our approach to implementing a line of sight algorithm for a continuous surface model on a mobile device is feasible, but has identifiable accuracy and human-computer interaction issues that could be addressed with future work. To reduce the user's uncertainty when attempting to direct the crosshair to a point of interest, a visual indication of when the LoS hits the DSM and how far away that is could be implemented in the form of a crosshair that dynamically changes its size according to distance. This allows the user to compare the visual image on the screen with the computed distance, to ensure that the device is not picking up a false artefact, or missing the DSM. The issue of the LoS hitting a foreground cell, particularly when using a coarse resolution DSM, could also be addressed by ignoring cells in the immediate area of the user. Given that the purpose of Zapp is for remote data capture this should not impede the user experience.

A common error was missing the DSM attempting to capture points towards the horizon such as mountains. Solutions to this include snapping the LoS to the model within certain tolerances, or possibly employing image-based techniques to identify the skyline and adjust the LoS accordingly. The latter option, however, introduces concepts of feature identification from the domain of machine vision, which brings new challenges in research and development. It may also change the nature of the Zapp application and the user's expectations of what it can achieve. The current system is a generic landscape logger, with no expectation that the system will attempt to recognise specific visually salient features. Nevertheless, given the specific issue with capturing peaks (or tops of buildings in urban settings) this may be one heuristic worth exploring.

For some applications, such as tourism, the query mode could be coupled with visual recognition of pre-specified landmarks, but this would increase complexity and require a continuous internet connection to perform visual feature recognition on an image database. Another enhancement might be to add cartographic data and provide a 'snap to map' mode that would return the nearest map feature to the target point.

In order to understand the utility of Zapp in other environments we plan to carry out tests in urban areas using LiDAR DSMs, including equivalent systematic accuracy assessments to those presented in this study.

## 8.0 Conclusion

The approach implemented in the Zapp application has been shown to be a viable option for the mobile capture of remote points of interest given the caveats related to current levels of accuracy. This simplicity of design and ease of operation was effective. A series of experiments has demonstrated that a combination of errors related to device sensors, the precision of targeting by users, and the representational fidelity of underlying terrain models, results in the technique being unusable for survey grade data capture and does not offer consistent spatial accuracies across a range of distances from the user. At any particular distance from the user the angle of incidence of the LoS to the terrain will result in variable impact of any directional uncertainties on the accuracy of any point captured. This function of distance and angle translates to how the landscape maps on to the field of view displayed through the mobile device screen, and the degree to which different points in a landscape scene can be discriminated. This in turn has informed our design of information layers to be used by Zapp in query mode and allowed us to define reasonable expectations when in capture mode. Further work is required to assess the usefulness of the approach in the context of a location based service in urban environments. We believe the technique offers a solution for remote geo-logging and query in the context of field studies or leisure activities, using any point on a continuous landscape representation rather than discrete mapped features.

## 9.0 Acknowledgements

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